63-4-2



# RESEARCH ON STORAGE TARGETS FOR CAMERA TUBES

A. H. BOERIO
Applied Physics Department

Interim Engineering Report No. 2

November 1, 1962 to March 1, 1963

Contract AF33(657)-8676

RESEARCH REPORT 63-912-253-R1



WESTINGHOUSE RESEARCH LABORATORIES
PITTSBURGH • PENNSYLVANIA

"The applied research reported in this document has been made possible through support and sponsorship extended by the Aeronautical Systems Division, Air Force Systems Command, United States Air Force, under Contract Nr. AF33(657)-8676. It is published for technical information only, and does not necessarily represent recommendations or conclusions of the sponsoring agency."

Research Report 63-912-253-R1 April 15, 1963

# RESEARCH ON STORAGE TARGETS FOR CAMERA TUBES

A. H. Boerio
Applied Physics Department

Interim Engineering Report No. 2

November 1, 1962 to March 1, 1963

Contract AF33(657)-8676

Aeronautical Systems Division
Wright-Patterson Air Force Base, Ohio

Westinghouse Research Laboratories
Pittsburgh 35, Pennsylvania

TABLE OF CONTENTS

## I. Introduction

The objective of this contract, as redefined in September, 1962, is to obtain information on Secondary Electron Conduction (SEC) targets for use in camera tubes employing Vidicon scan. It is specifically required that in addition to exhibiting high gain and short time lag, the target must be compatible with the materials and processes used in making photoemissive surfaces.

As reported previously[1,2], the SEC target exhibits high gain (of the order of 200) with essentially no inherent time lag in the signal generating mechanism[3]. The only lag that is observed with the SEC targets is associated with the readout process itself, governed by the RC time constant of the beam resistance and the target capacity. While large capacity is a characteristic of the SEC target, this capacity is still small enough to permit complete readout within one frame time (1/30 sec).

The evaporation parameters used in forming the low density KCl layer for these targets are identical to those used for making high gain Transmission Secondary Emission (TSE) dynodes[4]. It is yet to be determined whether or not this evaporation technique yields optimum target performance and further, how the electrical characteristics depend upon the evaporation parameters. Before considering the answers to these two questions, it was judged more important to eliminate uncertainties involved in employing the SEC target in camera tubes using direct beam readout. These uncertainties are: target compatibility with various photoemissive surfaces and the ability of the target to withstand exposure to intense signals.

Experience gained from this and parallel programs demonstrates that the SEC target is compatible with CsI and CsTe, ultraviolet sensitive photosurfaces, as well as S-11 and S-20 photosurfaces, all internally processed. Details are given in Section II.

The SEC target in its present form cannot be used in conjunction with conventional vidicon guns in which the wall screen (gun electrode adjacent to target) is operated at its normal voltage, without either limiting the maximum signal to which the tube is exposed or risking permanent damage to the target. There are in general three approaches to this problem, discussed in detail in Section IV. The method utilizing a control grid between the target and wall screen has been selected as a most promising approach and experiments employing such a grid have been initiated.

## II. Target-Photocathode Compatibility

Two tubes with internally processed S-11 (Cs-Sb) photocathodes were made under this contract. Neither tube showed indications of adverse effects on target performance due to the photocathode processing. Although the photocathodes of these tubes were of the flip-over type, several tubes with S-20 photocathodes processed in the normal manner (Contract AF33(657)-9190) were also free of adverse photocathode-target interactions. Experience gained from a parallel program shows that the SEC target is also compatible with Cs-I and Cs-Te photocathodes. In view of these results, it seems highly unlikely that other commonly used photocathodes should present a compatibility problem. Thus, no further target-photocathode compatibility studies are planned at this time.

## III. Tube Performance

The performance of the first sealed off tube with an S-11 photocathode has been described in detail in the previous interim report[2]. During the course of further measurements, the target of this tube accidentally ruptured, probably due to a faulty target connection.

A second tube, identical to the first, was made during this reporting period. At target voltages up to 15 volts, the target of Tube No. 2 is essentially free of blemishes and can be completely erased within 2 or 3 frame times. At higher target voltages, several blemishes appear and the target exhibits a time lag due to solid state conduction. The performance of this tube can be judged by Fig. 1, where limiting resolution versus photocathode illumination curves are plotted. These measurements were made with a 2870°K light source and USAF 1951 test patterns of 100% and 14% contrast. In both cases, the target was operated at 15 volts and the image section at 8 KV. Continuous scan with 1/30 second frame time was used for these measurements.

The photocathode response of Tube No. 2 is only 10 μa/lumen as compared to 25 μa/lumen for Tube No. 1, whose curves for 100% scene contrast at continuous scan and for 30 seconds integration time are also included in Fig. 1. A comparison between the two 100% curves under continuous scan shows that in order to see the same resolution, Tube No. 2 requires 2.5 times more light than Tube No. 1. Based on only the photoresponse, this is exactly what one would expect. However, the equivalent noise current of the camera chain used to measure Tube No. 2 was about 1.5 times the noise current of the chain used for Tube No. 1. Since all other conditions were identical, this means that the target in Tube No. 2 has a slightly higher gain than does the target of Tube No. 1.

Because the KCl target has not shown adverse effects on S-20 photosurfaces, known for their sensitivity to foreign materials, the relatively poor photoresponse of both S-11 tubes seems due to improper photocathode processing rather than the presence of the KCl target.

1. Target Gain

Measurements made under previous and parallel investigations indicate that gain variations from target to target are related to the maximum target backplate voltage that can be applied without resulting in solid state conduction and its associated time lag. Those targets which can be operated at a maximum voltage of the order of 50 volts exhibit gains of approximately 100 at 15 volts, and gains of about 250 at 40 volts. Those targets which must be operated at somewhat lower voltages generally exhibit lower gains. Presumably these "low voltage targets" are thinner and cannot absorb as much energy from the primary beam. Measurements designed to test this hypothesis are planned.

The maximum tolerable target voltage for Tube No. 2 is 15 volts. Thus, one would expect a lower gain from this thinner target as compared to a normal target. The target gain, calculated below, bears this out.

The 100% scene contrast curve in Fig. 1 shows that a photocathode illumination of $6.0 \times 10^{-5}$ foot candles is required in order to resolve 50 TV lines/inch. It can be shown that at this point the tube performance is system noise limited. Thus the "noise charge", $Q_n$, with which the signal on a target element must compete is given by

$$Q_n = I_n \Delta t \tag{1}$$

where $I_n$ is the equivalent rms noise current of the video amplifier and $\Delta t$ is the dwell time of the readout beam on the signal area.

The signal charge is given by

$$Q_s = J_s \cdot a \cdot t \cdot G \tag{2}$$

where $J_s$ is the photocathode current density measured within the signal area, a, t is the integration time, and G is the target gain. The "noise equivalent charge", $Q_n$, and the signal charge, $Q_s$, are related by the minimum signal to noise ratio, $SNR_o$, necessary for detection:

$$Q_s = SNR_o Q_n \tag{3}$$

Equation (1) through (3) along with the fact that in continuous scan

$$A \Delta t = at, \tag{4}$$

where A is the total scanning area, yield the following expression for gain,

$$G = \frac{SNR_o \, I_n}{J_s \, t \, A} \qquad (5)$$

The $6 \times 10^{-5}$ foot candles illumination on the 10 µa/lumen photocathode results in a signal current density of $6.5 \times 10^{-13}$ amps/cm$^2$, and a limiting resolution of 25 line pairs per inch or 27 line pairs over the 1.1 inch scan width. Measurements made by Coltman and Anderson[5] show that the minimum signal to noise ratio is given by:

$$SNR_o = \frac{N \alpha}{615 \, (\Delta f)^{1/2}} \qquad (6)$$

where N is the threshold resolution in line pairs per picture width and $\Delta f$ is the system bandwidth in megacycles. The factor, $\alpha$, is unity if the observer is permitted to see 7 or more line pairs. Their measurements yield an $\alpha$ of approximately 2 for the case when only 3 line pairs are presented as was the case in obtaining the data of Fig. 1 with the Air Force Test Pattern. Since a bandwidth of 11 megacycles was used, Equation (6) yields an $SNR_o$ of 0.028. The appropriate values of $I_n$, t, and A, $6.5 \times 10^{-9}$ amps, 1/30 second, and 5.4 cm$^2$ respectively, along with the values cited for $J_s$ and $SNR_o$ yield, from Equation (5), a gain of 50. Though the accuracy of such a calculation is limited, primarily by the accuracy of the curve of Fig. 1 itself, this result is quite reasonable if compared with direct gain measurements on "thin" targets.

2. Low Contrast

The SEC target exhibits a high degree of uniformity and presents no fixed pattern noise which would limit the low contrast performance. As can be seen from Fig. 1, an illumination increase of approximately 10 was needed in going from 100% to 14% scene contrast in order to see the same resolution. Assuming a target gain of 50, the rms shot noise current due to quantum fluctuations in the signal itself is readily calculated. At $8 \times 10^{-2}$ foot candles, the shot noise current flowing through the video load resistor is about equal to the amplifier noise current ($6.5 \times 10^{-9}$ amps) while at an illumination of $8 \times 10^{-4}$ foot candles the shot noise current is approximately one-tenth the amplifier noise current.

If the shot noise were indeed negligible, a decrease in scene contrast would effect only the signal so that a decrease from 100% to 14% contrast would require an increase in illumination of 100/14, or about 7, in order to see the same resolution. If, on the other hand, the amplifier noise were negligible compared to the shot noise, it follows[6] that

$$SC^2h^2 = \text{Constant} \qquad (7)$$

where S is the photocathode brightness, $h^2$ is the area of a resolution element and C is the threshold contrast defined by the smallest detectable change in brightness, $\Delta S$, divided by S. In this case, a change in scene contrast from 100% to 14% requires $(100/14)^2$ or about 50 times more light to achieve the same resolution.

Since the illumination range covered by the 14% contrast curve is that in which the shot noise becomes significant, but where the amplifier noise is predominant, it follows that the increase in light needed in going from 100% contrast to 14% contrast will be slightly greater than a factor of 7. The measured value of about 10 indicates, then, that at scene contrasts at least as low as 14% the tube yields the theoretically expected performance and is not limited by the target.

## IV. Target Stability

In order to facilitate a thorough understanding of the target stability problem, a brief review of the target mode of operation is in order.

The target backplate is maintained positive (of the order of 20 volts) with respect to the readout gun cathode which is normally grounded. The readout electron beam charges the exit surface of the target down to cathode potential, thus polarizing the target. At the onset of a signal, high energy photoelectrons, many secondary electrons are created within the KCl layer. Due to the polarization of the target, initially most of these electrons are collected on the backplate creating within the KCl layer a net positive charge which is the stored signal. This process continues to integrate information until the KCl layer reaches backplate potential. At this point, the number of transmitted secondary electrons becomes significant. These escaping electrons add to the information stored by charging the KCl layer to more positive values. This additional charging is identical to that which takes place when the KCl layer is employed as a high gain dynode[7]. If the charging process is not interrupted by the scanning beam, the potential of the KCl layer will reach an equilibrium value, $V_E$, of the order of 50 volts positive with respect to the target backplate. This value depends on several factors, one of which is the voltage applied to the collector electrode, i.e., the wall screen of the scanning gun.

If the intensity of the signal and the integration time is such that the target assumes equilibrium potential, the readout beam will land with an energy of $e(V_E + V_T)$ electron volts, where $V_T$ is the target backplate voltage. If this energy is in excess of first crossover for secondary electron emission in reflection, which was measured to be 15 eV, the readout beam will not return the KCl layer to gun cathode voltage but will charge it to the voltage of the collector electrode, $V_C$. In this event, the voltage across the KCl layer is $V_C - V_T$. The maximum field the target can withstand varies over the target area as well as from target to target. Generally, breakdown occurs at approximately 80 volts and results in a physical hole in the target. Since the collector electrode is the wall screen of the electron gun and must therefore be operated at a relatively high potential (of the order of 300 volts), the target would be severely damaged under these circumstances. If, on the other hand, $(V_C - V_T)$ is less than 80 volts, normal operation could be resumed by temporarily reducing $V_C$ to a value below first crossover in which case the readout beam would return the KCl to gun cathode potential.

Thus, there are really two problems. The first, and most important, is that of preventing the target from reaching breakdown potential under all levels of illumination. Secondly, it is desirable to find a means of preventing the target from reaching first crossover potential so that the tube may be operated continuously under all levels of illumination.

The various approaches to these problems can be classified as modifications in the tube or as modifications in the target itself. In general, a solution involving only modifications in the operating parameters of the target is preferable, as such a target could then be readily used with all existing scanning guns, be they electrostatic or electromagnetic.

1. Tube Modifications

The maximum potential that the KCl layer might assume could be limited to:

a) the cathode potential of an auxiliary electron gun used for flooding the target

b) the potential of an auxiliary grid inserted between the target and the last readout electrode.

Because the auxiliary grid would require only slight modifications in the internal tube geometry, this approach was chosen over the more complex tube needed to accommodate an auxiliary gun. Further, when compared to the solution involving target modifications discussed below, inserting an auxiliary grid requires considerably less effort and yields a higher probability for success. For this reason, it was chosen for first consideration.

During this reporting period, a demountable target test stand was modified to accommodate an auxiliary grid spaced 10 mils from the target. This all electromagnetic test stand will be used to determine the practicability of the auxiliary grid for sealed-off tubes.

The target to grid spacing must be small in order to avoid an increase in the flight time of the readout beam electrons. The large target shunt capacity associated with the close spaced grid can lead to microphonics caused by vibrations in the grid or target. Also, the noise current of the compensated amplifiers normally used with direct beam readout tubes increases almost linearly with the target shunt capacity[8]. A means by which these difficulties can be avoided is to connect the auxiliary grid directly to the target.[9] In this mode of operation, the desired grid voltage fixes the target backplate voltage. Thus, the ability to fabricate a target exhibiting high gain at a pre-selected target voltage is required in order to make this method practical.

## 2. Target Modifications

In order to keep the target from reaching crossover potential, it is necessary that

$$V_T + V_E < V_1 \tag{8}$$

where $V_T$ is the target backplate potential, $V_E$ the equilibrium voltage across the KCl layer, and $V_1$ the voltage at which first crossover occurs.

In order to utilize the maximum gain capability of the target, it is necessary to operate the target backplate at voltages of up to 40 volts. The equilibrium voltage has been measured in dynode applications[10] and can be as high as 80 volts, depending primarily on the external electric field which is applied to the KCl layer.

The external electric field is given by $(V_C - V_E)/d$, where $V_C$ is the voltage of the collector electrode (wall screen), and d is the distance between target and mesh. When the collector is at a potential of 100 volts and spaced at a distance of 100 mils, the equilibrium potential is found to be of the order of 50 volts. Increasing the collector voltage beyond 200 volts generally results in the possibility of breakdown across the KCl layer due to a corresponding increase in the exit surface potential.

In order, then, to satisfy the somewhat arbitrary goal of exposing the target to a 300 volt mesh at a spacing of 100 mils, it is necessary first to reduce the equilibrium voltage under these conditions to a value below breakdown (approximately 80 volts) and then proceed further to satisfy Equation (8) by reducing $V_T$ or $V_E$ or both and/or increasing $V_1$.

Since, on a microscopic scale, the surface of the low density KCl layer is of its very nature highly irregular, the possibility of increasing $V_1$ while retaining the necessary low density structure is remote and attempts to do so are not planned.

In order to modify the target so as to reduce $V_E$ to values of the order of 10 volts, one has to find a means of reducing the TSE gain of the target without appreciably degrading the conduction gain. A possible way to accomplish this is by increasing the density of the KCl in the outer portion of the layer while leaving the density unchanged in the region immediately adjacent to the backplate. A limitation to the density increase that could be tolerated is imposed by the fact that the readout beam must penetrate at least a portion of this higher density region in order to reach the stored charge which lies within the KCl layer[1]. It is not certain whether this limitation will permit a sufficient reduction in TSE gain.

The third target parameter which must be altered in order to satisfy Equation (8) is the target backplate voltage, $V_T$. Experience gained from targets made thus far indicates that those targets which do exhibit reasonably high gains at relatively low target voltages, 2 to 10 volts, are "thinner"; the mass of KCl per unit area as measured by electron beam penetration is lower and the target capacitance is higher. Since these targets were supposedly made under the same evaporation parameters as the thicker ones, it is clear that a higher degree of control over the evaporation technique is needed before "low voltage targets" can be made consistently.

## V. Future Plans

The feasibility studies on using an auxiliary grid, either connected to or insulated from the target, to achieve target stability will be confined to electromagnetically focused tubes. At the completion of these studies, efforts will be made to achieve reasonable reproducibility from target to target. Such efforts will involve experiments designed to yield the relationship between the electrical parameters of the target, primarily the gain-backplate voltage characteristic and the capacity, and the target structure. In order to fabricate targets with the desired electrical characteristics, it will then be necessary to relate the evaporation techniques to the target structure to include the density distribution across the KCl layer as well as the thickness. These studies should be complete before attempts to make self-stabilizing targets are initiated. However, instead of waiting until this somewhat lengthy program is completed, several direct attempts to make a self-stabilizing target by reducing the TSE target gain without degrading the SEC gain are planned.

## VI. Technical Personnel

Due to a concurrent program, contract AF33(657)-9190, the time that could be devoted to this contract was limited to that shown below. Every effort will be made to accelerate the program to the extent that the completion date can be met.

| | Approximate hours worked during period |
|---|---|
| G. W. Goetze | 180 |
| A. H. Boerio | 160 |

Acknowledgment

This work is being carried out under the supervison of Dr. G. W. Goetze, who has made many contributions to the program.

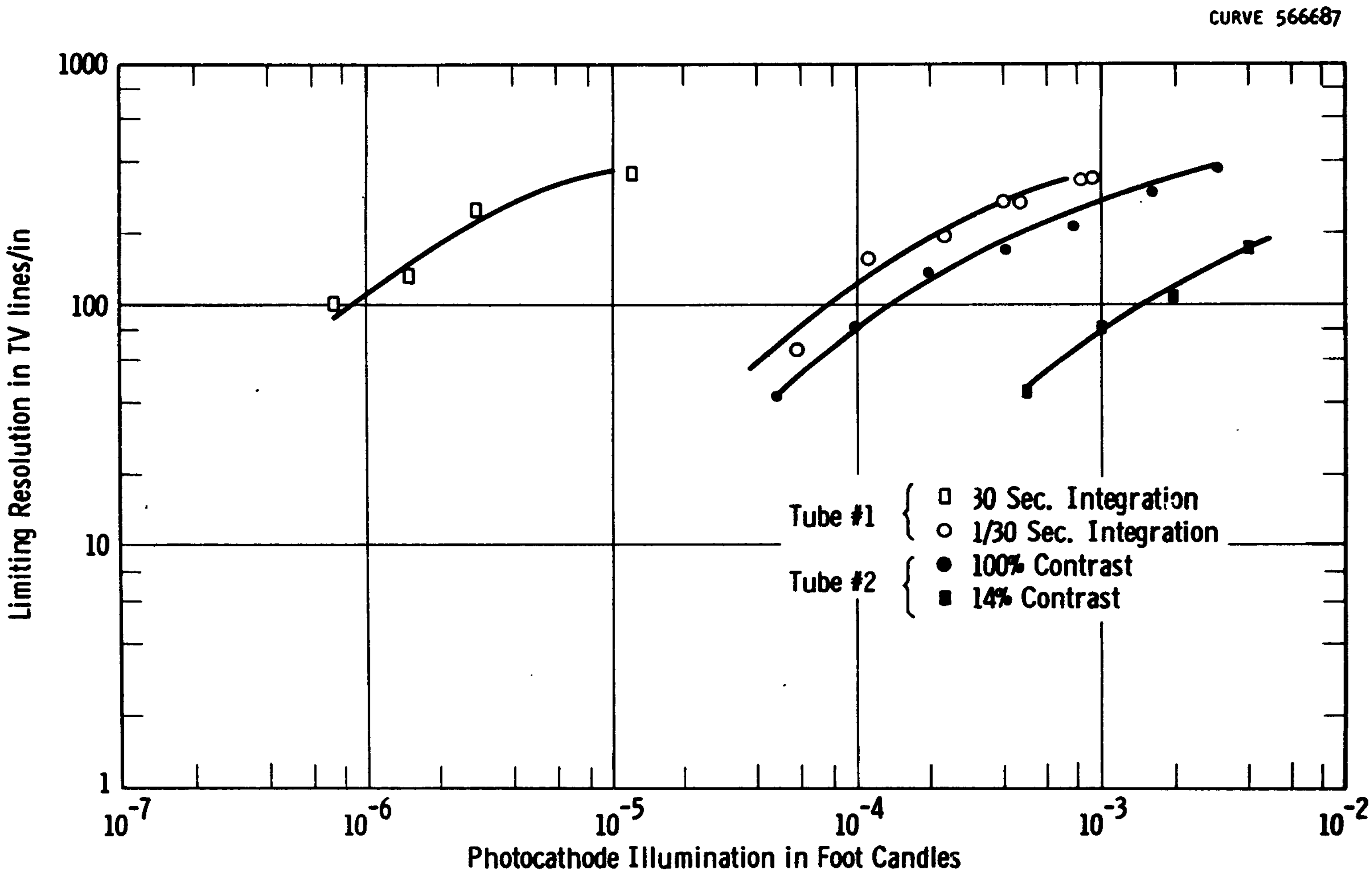


Fig. 1 - Limiting Resolution vs. Photocathode Illumination

## REFERENCES


1. G. W. Goetze, et al. Applied Research on TSEM Image Amplification Camera Tube. Technical Documentary Report No. ASD-TDR-63-84, January 1963.

2. G. W. Goetze, A. H. Boerio. Interim Engineering Report No. 1, Contract AF33(657)-8676, January 1963.

3. E. J. Sternglass and G. W. Goetze. IRE Trans. on Nuclear Science, Vol. NS-9, No. 3, June 1962.

4. G. W. Goetze, A. H. Boerio. Third Quarterly Progress Report, Contract DA-44-009 ENG-4858, USAERDL, Fort Belvoir, Va., Sept., 1962.

5. J. W. Coltman, A. E. Anderson. Proc. IRE 48, 5, p. 858, May 1960.

6. A. Rose. Advances in Electronics I, p. 131, 1948.

7. G. W. Goetze, A. H. Boerio. First Quarterly Progress Report, Contract DA-44-009 ENG-4858, USAERDL, Ft. Belvoir, Va., April 1962.

8. G. M. Glassford. Fundamentals of Television Engineering, p. 111-124, McGraw-Hill, 1955.

9. R. R. Beyer and A. H. Boerio. Patent Disclosure 58,305.

10. M. Green. Fifth Progress Report, Contract DA-44-009 ENG-4858, USAERDL, Fort Belvoir, Va., April 1963.